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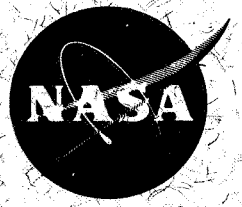
CLEAN ROOM FACILITIES FOR ASSEMBLY, EXPLORER XXXV SPACECRAFT

FRANCIS N. LeDOUX

DECEMBER 1967



GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

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ABSTRACT

Particulate contamination is extremely important to the engineers and scientist. Costly delays and failures on past spacecraft projects have been attributed to inadequate or, lack of contamination control. Biological contamination of lunar and planetary spacecraft are of considerable concern to the NASA Headquarters Office of Planetary Quarantine which requires automated spacecraft be biologically decontaminated to a level of no more than 2.59×10^6 viable spore forms on spacecraft at time of launch.

In order to reduce particulate and biological contamination of the Explorer XXXV spacecraft, clean-room facilities of various clean-room classes were used to conduct a specific task. Debris generating operations were performed in uncontrolled areas with protection afforded to flight hardware in the near vicinity of debris generation. Decontamination, conformal coating, and encapsulation of electronics were performed in a class 10,000 conventional clean-room. Spacecraft build-up, some engineering tests were conducted in a class 100,000 conventional clean-room. Electronic systems check-out in the field, cleaning and decontamination of small hand tools, instrument assembly, and/or functional operation tests, final spacecraft decontamination and assembly, and bioassying were conducted in a class 100 bio-clean room environment. All clean-room areas were restricted to number of personnel working in area, clean-room dress, deportment, and procedures.

On the basis of the bio-records it was determined that the surfaces of the Explorer XXXV spacecraft contained not in excess of 9×10^5 microorganisms prior to decontamination. This low level of contamination has been attributed to the assembly, test, and integration of the spacecraft in the various clean-room environments and the contamination controls utilized.

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CLEAN ROOM FACILITIES FOR ASSEMBLY, EXPLORER XXXV SPACECRAFT

INTRODUCTION

Many items of spacecraft hardware are manufactured in various locales in the country and shipped to the Goddard Space Flight Center for use in building a spacecraft system. The interval of time introduced between the inspection of components after manufacturing phase and the time the component is in process of assembly or mechanical integration is one of the most important phases in component reliability. During these time intervals it is most probable that satellite component parts, subassemblies, and completed assemblies of flight units will become damaged or made less reliable. Each day that satellite components, satellites, and/or space probes are exposed in the laboratory to a hostile environment such as the generation of particulate and biological contamination, the probability that they will be harmed and made less reliable increases.

Particulate contamination is of extreme importance to the engineers and scientists. Costly delays and failures on past spacecraft projects have been attributed to inadequate or the lack of contamination control.

Biological contamination of lunar and planetary spacecraft and/or their components are of considerable concern to the NASA Headquarters Office of Planetary Quarantine which requires automated spacecraft with a mission in the near vicinity of the moon be biologically decontaminated to a level of no more than 2.59×10^6 viable spore forms on board at time of launch.

Because of these requirements which relate to particulate and biological cleanliness, it became necessary to provide controlled environmental facilities that would allow various levels of clean environments in which to perform specific tasks on the Explorer XXXV spacecraft at NASA Goddard Space Flight Center and in the field during the launch check-out phase.

This paper will outline the environments and physical features of the facilities in the Mechanical Systems Branch, Goddard Space Flight Center used in the Explorer XXXV spacecraft decontamination (i.e., during structural build-up, mechanical integration, assembly and biological sampling of hardware and spacecraft). This paper will also indicate the control and environments to which the spacecraft was subjected in the field and the results of biological decontaminating the Explorer XXXV spacecraft (presently in lunar orbit), which was launched 19 July 1967, Cape Kennedy, Florida.

ASEPSIS CONTROL DURING ASSEMBLY

Spacecraft Preparation Area

The debris generating operations that were performed on a component or the spacecraft structure were conducted in the Spacecraft Preparation Area. This area was 25' x 20' and contained drill presses, filing machine, punch press, and sundry hand power tools. When it was required to custom fit a component to a structure and the operations of filing, drilling, or scraping of metal were necessary, a shield was built to protect other components from falling metallic particles. In addition, a vacuum cleaner was employed to gather loose chips as generated. The inlet of vacuum cleaner inlet nozzle was placed in the immediate area worked upon. Just prior to removal of a spacecraft or a component from this area it was vacuumed and wiped down with an alcohol dampened cotton cloth wiper. Figure 1 shows such an operation being performed.

The spacecraft was then transported on its dolly to the Hi-Bay Clean-Room Complex where assembly, integration of components, decontamination, and engineering tests were conducted.

Hi-Bay Clean-Room Complex

The Hi-Bay Clean-Room Complex consisted of a 100,000 class, conventional clean-room, approximately 70 feet square, 24 feet high. Within this clean-room area are class 100 portable vertical laminar flow units which are expandable in multiples of 4' x 8' units and class 100 horizontal flow benches. The vertical flow units were used to house the spacecraft when not worked upon in the class 100,000 area. The spacecraft was always precleaned before it was placed under the down flow units. This cleaning consisted of wiping and vacuuming the surfaces. The down flow units were also used to perform instrument integration, decontamination, and bio-sampling of components. The flow benches were used when assembling delicate mechanisms and the cleaning thereof at each stage of assembly. After the spacecraft was mechanically integrated it left the clean-room area for electronic integration and/or systems environmental tests. At that time the spacecraft was protected by a strippable coating which was applied only to the exterior exposed surfaces.

Figure 3 is another view of the Hi-Bay Clean-Room Complex. It shows in more detail one of the class 100 vertical down-flow units. The unit in the right foreground was used by the lead technician when performing a decontamination operation on the spacecraft. It was also used to store spacecraft when not worked upon and by the biologist when taking bio-samples and preparing sterile media.

The electronic circuit modules, electrical connectors, and wiring harnesses that were to be cleaned, decontaminated, conformal coated, and/or encapsulated were first precleaned with an aerosal of ethyl alcohol to remove deposits of solder

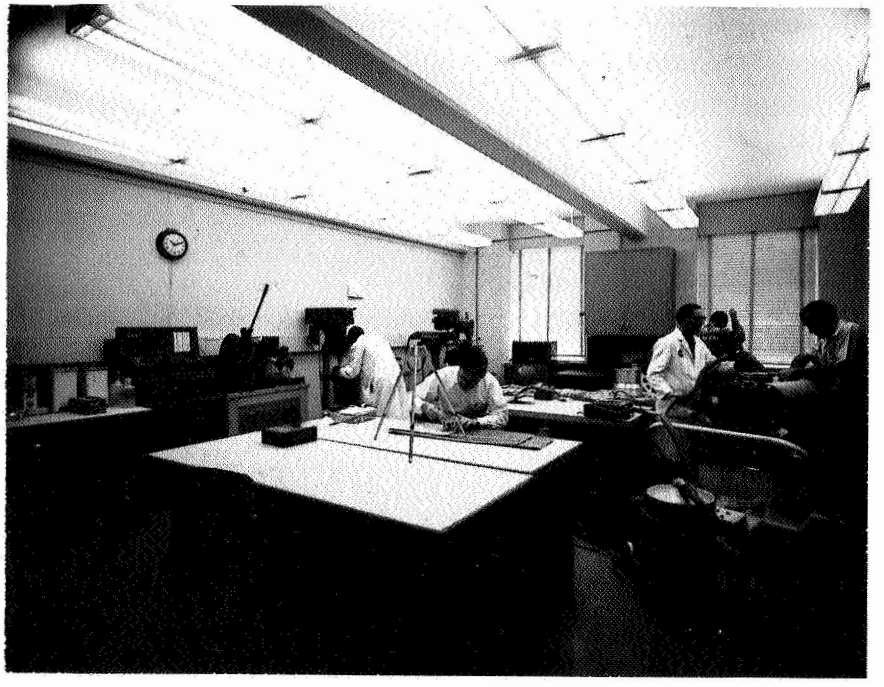

Figure 1. Spacecraft Preparation Area

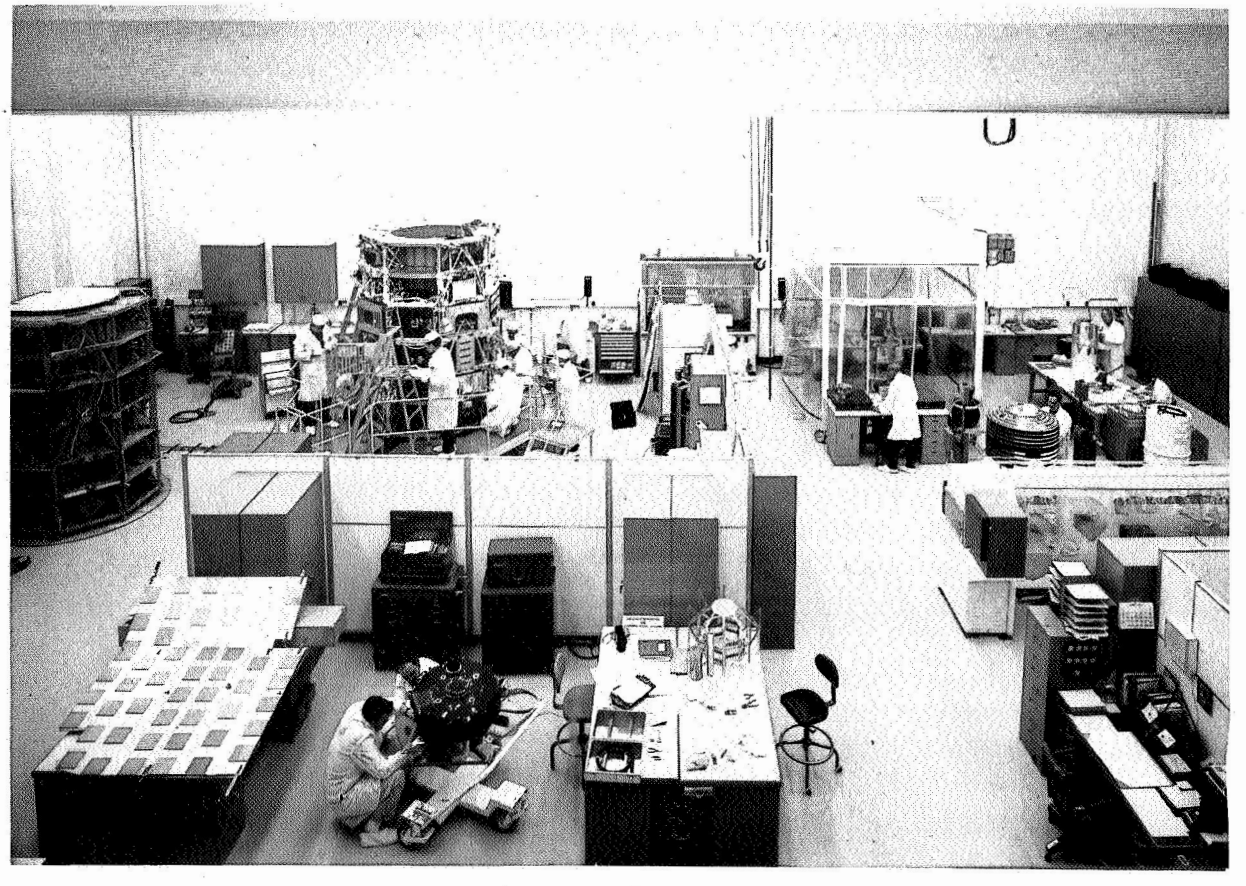

Figure 2. Hi-Bay Clean-Room Complex

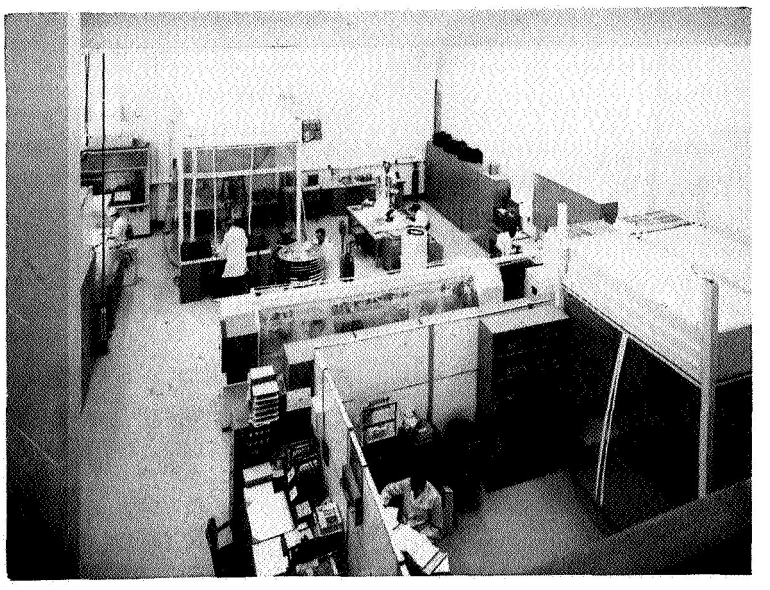

Figure 3. View of Down-Flow Unit in the Hi-Bay Clean-Room Complex

flux and/or residual water laquer remaining on circuit boards after their fabrication. The circuit modules were then injected into the class 10,000 area of the Bio-Clean Complex.

Bio-Clean-Room Complex

Tests conducted by the Structures and Mechanical Application Section at Goddard Space Flight Center have indicated that particulate contamination in the facility exceeds the NASA required levels in all area of the complex.

The facility consists of four separate rooms with an area of 600 square feet (Figure 4). Room A is a personnel preparation room with a brush vacuum mat at the entrance of the door to clean shoe bottoms. A closet with sterile clothing and a surgical wash basin are included. Room B, a small anteroom, is an airlock with a built-in air shower. The air shower has a 40-mph wind that lasts for 25 seconds and is designed to remove lint and skin scales from the skin and clothing of personnel. Room C is a work area containing decontaminating and monitoring equipment, a positive-pressure air system and an interlocking system on the doors that allows one door to open at a time. This arrangement prevents the pressurized air system from being overridden.

Room D is a bio-clean room where satellites are decontaminated. An unusual feature of this room is a monitoring camera which photographs the satellite and personnel every 5 seconds. This feature was included to check on faulty operations that may occur while in the bio-clean room. Horizontal, laminar-flow air emanates from a 14-foot wall via modules with Cambridge high efficiency particulate air (HEPA) filter units. Filtration tests confirmed a rating for this room between 0 and 66 particles of 0.5 micron and larger per cubic foot of air. Walls are of prefabricated panels with 4-inch plastic foam insulation. Epoxy-coated steel forms the

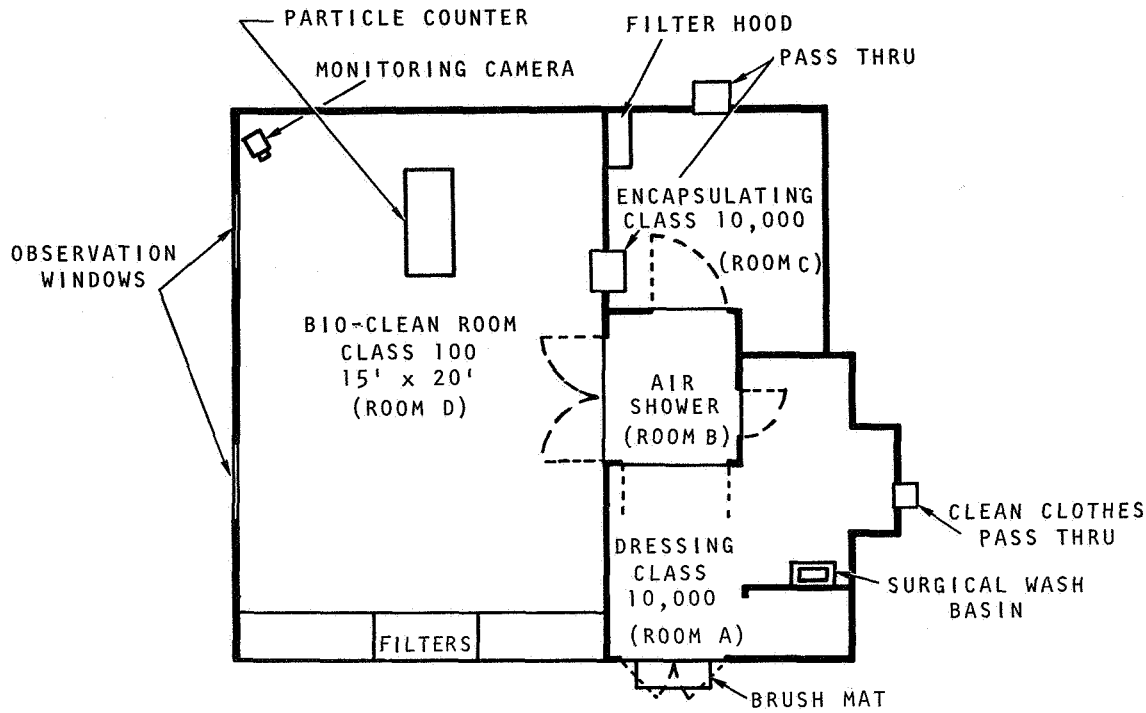

Figure 4. Bio-Clean Room Complex

interior surfaces. A completely lighted ceiling gives a shadowless, 200-foot-candle illumination at working levels. There are a minimum of 20 air changes per hour at a controlled temperature range of 67° F to 77° F and a relative humidity level of 40 to 45 percent. A constant temperature of 72° F was maintained. A central built-in wall-type vacuum system is provided in all four rooms, along with observation windows that are double-paned and sealed. Also included are pass-through chambers containing interlocking doors to assure maintenance of a positive air-pressure when parts are brought into the room.

During any operation in a clean room environment where a component is handled or a test is being performed in the spacecraft it is highly probable that particulate and biological contamination, from personnel and/or the task used in conducting tests, will be released and transferred. In order to minimize the release and/or transfer of this contamination it was deemed necessary that a set plan or procedure (see Appendix) be followed by personnel working in a clean room area in order to reduce to the lowest level the particulate and biological population.

Clean-Room Assembly Tools

Tools used in the clean room during spacecraft assembly and/or field testing of the system were first precleaned by wiping off gross contamination with cotton wipers. Tools were then placed into a wire mesh basket and exposed to Freon TF vapor cleaning for 25 minutes. They were then placed in an ultrasonic bath containing a 50% solution of isopropyl alcohol (C_3H_7OH) and sonicated for 25 minutes at 25 kc/sec. After removal from the solution they were placed in an oven which was

preheated to 55° C. They remained in this environment for 25 minutes. All tools were then packaged and sealed in sterile plastic sheet material. These packs were again packaged so as to have tools double packed and sealed. The outer package was removed just prior to injecting tools into the Goddard Down Flow Unit for use in spacecraft assembly.

Packaging and sealing of cleaned tools are performed in what we call a 'white bench' (Figures 5, 6 and 6a). There are three areas in the bench enclosure that are ultra-clean working areas, i.e., ultrasonic cleaning, assembly and/or inspection, and clean storage. This environment, having filtration efficiencies in excess of 99.95% with particles as small as 0.3 microns, meets class 100. It is temperature and humidity controlled and maintains a positive pressure in each working area.

ASEPSIS CONTROL OF SPACECRAFT DURING CONDUCTANCE OF FIELD TESTS, CAPE KENNEDY, FLORIDA

Introduction

It is a requirement of the NASA Headquarters Planetary Quarantine Officer that potential lunar landing spacecraft be handled, tested, and prepared for launch over a period of not less than T-20 days in spaces conforming to the NASA Laminar Flow Clean-Room Specifications, which state that they shall be of the laminar flow type, air movement from ceiling to floor, and shall conform to Federal Specifications 209 class 100 clean-room standards. This requirement could not be met completely as spacecraft had to be in two test areas that could not be made to conform to clean-room specifications. When the spacecraft was undergoing tests in these areas the spacecraft was protected from particulate and bio-contamination by an asepsis covering that had previously been sterilized.

Cape Kennedy Clean-Room Facility

The facility at the Cape was a class 10,000 clean-room complex consisting of both horizontal laminar flow and conventional areas. The Goddard class 100 laminar down-flow unit was placed into the laminar flow clean-room 10 feet from the face of final filtered air inlet. The electronic check-out of all flight instrumentation and experiments were conducted while spacecraft was in the class 100 environment. The personnel conducting the tests in the clean room facility were limited to a maximum of 5 at one time in the class 10,000 area and no more than 2 of these at any one time in the Goddard down-flow unit. The personnel conducting experiment tests in these areas were subjected to restrictions of clean-room deportment and garment dressing.

Gantry Air Cooling-Hat Shroud

After the completion of tests in the Spin Balance Facility an asepsis cover previously sterilized with ethylene oxide compound was placed over the entire

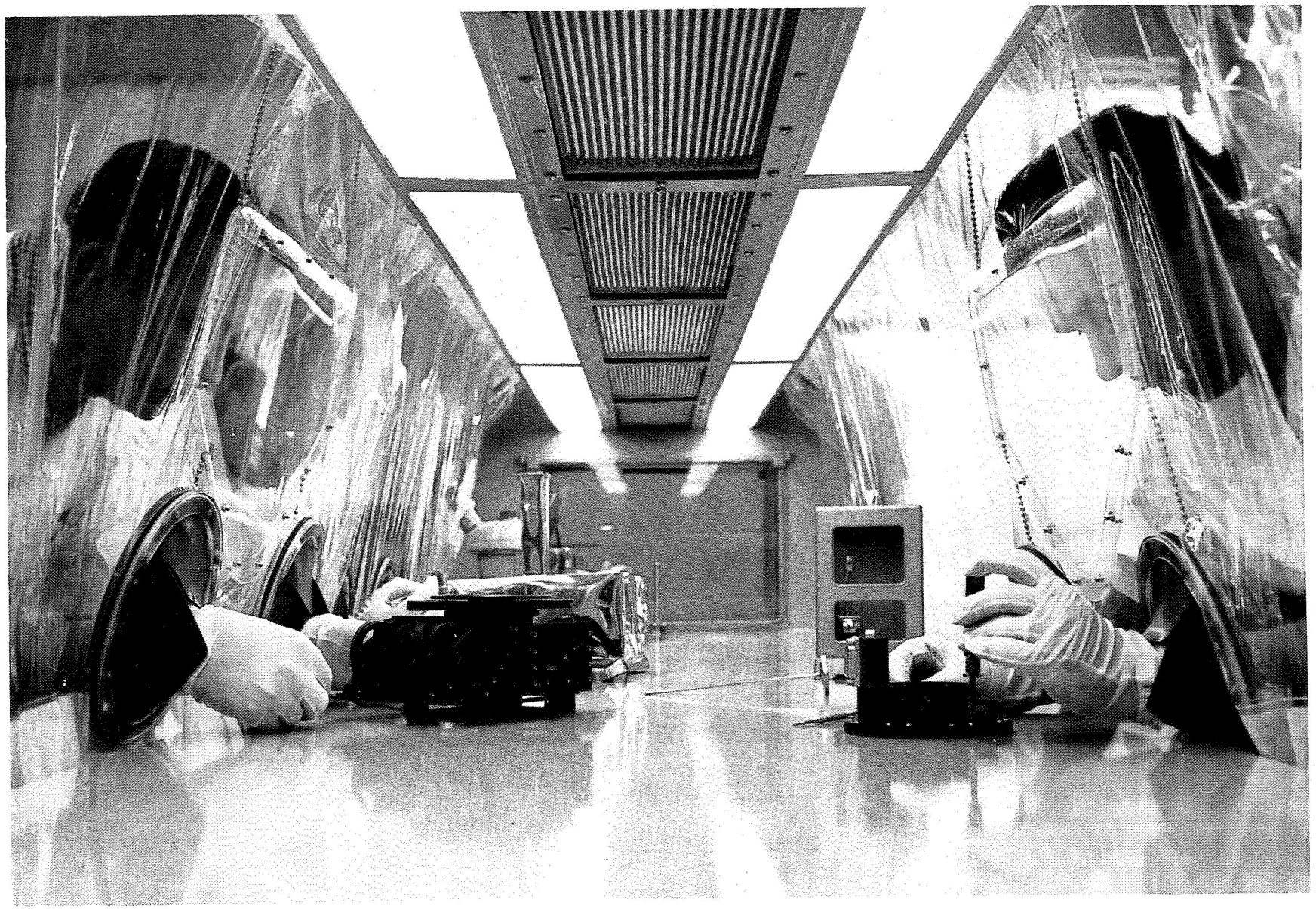

Figure 5. White Bench, Assembly Operation

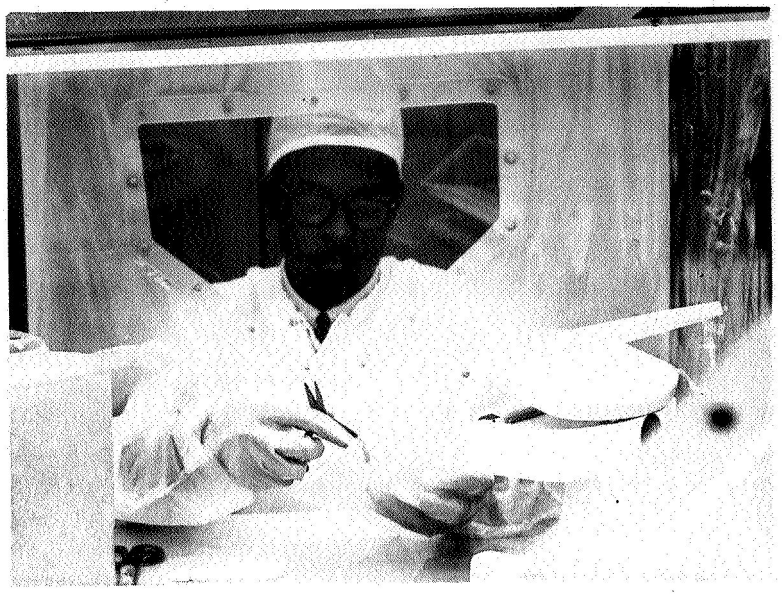

Figure 6. Technician Inserting Cleaned Tool into Plastic Envelope

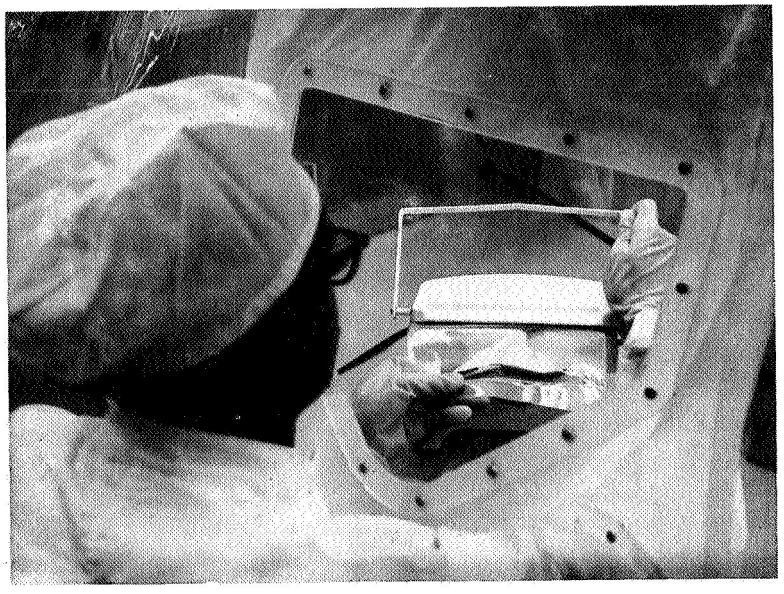

Figure 6a. Technician Sealing Plastic Envelope Containing Tool

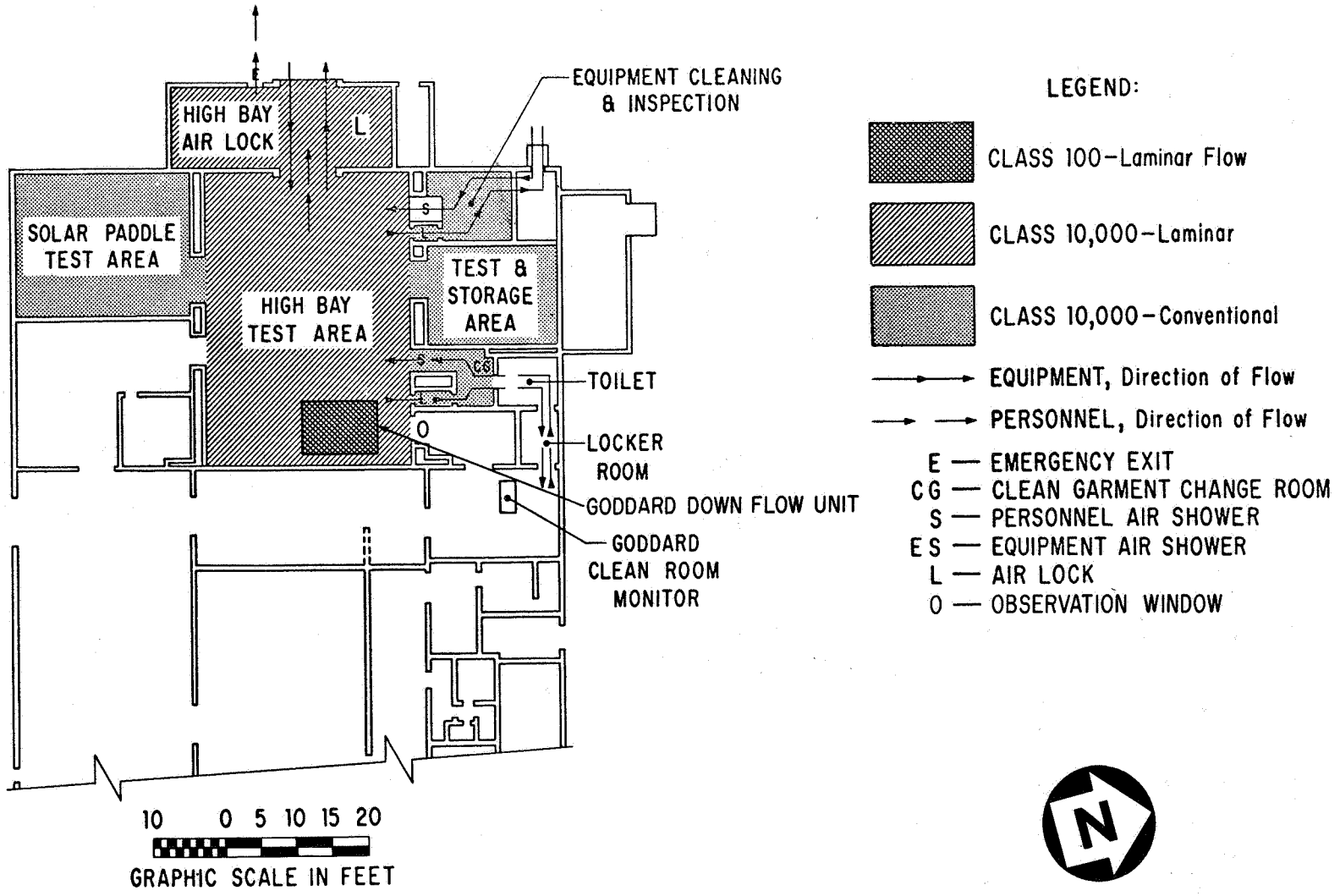

Figure 7. Spacecraft Clean Rooms, Building "AE" KSC

spacecraft (Figure 8). The spacecraft was canned and the container pressurized with slight positive pressure of dry gaseous nitrogen and was delivered to the launch gantry.

The transfer container was removed and the asepsis bag allowed to remain intact over the spacecraft until the air cooling-hat shroud (Figure 9) was placed in operation. The air into the cooling hat shroud met class 100 requirements. It was temperature controlled and passed through a diffuser designed to assimulate a vertical laminar flow of filtered air over the spacecraft. The spacecraft was in this environment until separation of service umbilical at time of lift-off.

The removal of the protective strip coating, final decontamination and sample taking for bio-assays were performed on spacecraft while in the cooling-hat shroud.

Results of Bio-Decontamination

On the basis of the Goddard Bio-Records (see Table 1) it was determined that the surfaces of the Explorer XXXV spacecraft contained not in excess of 9×10^5

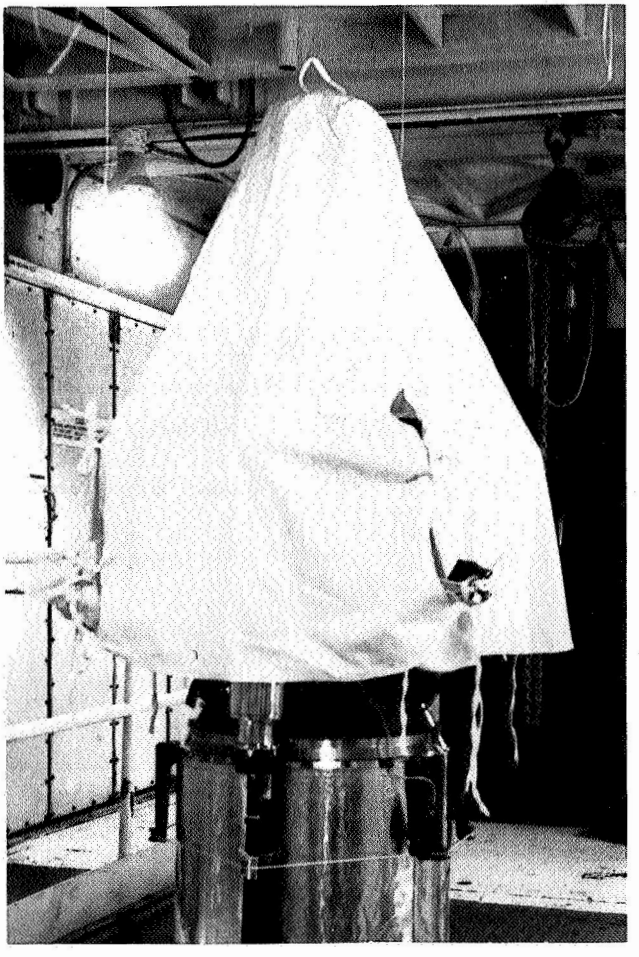

Figure 8. Asepsis Cover on Spacecraft at Spin Balance Facility

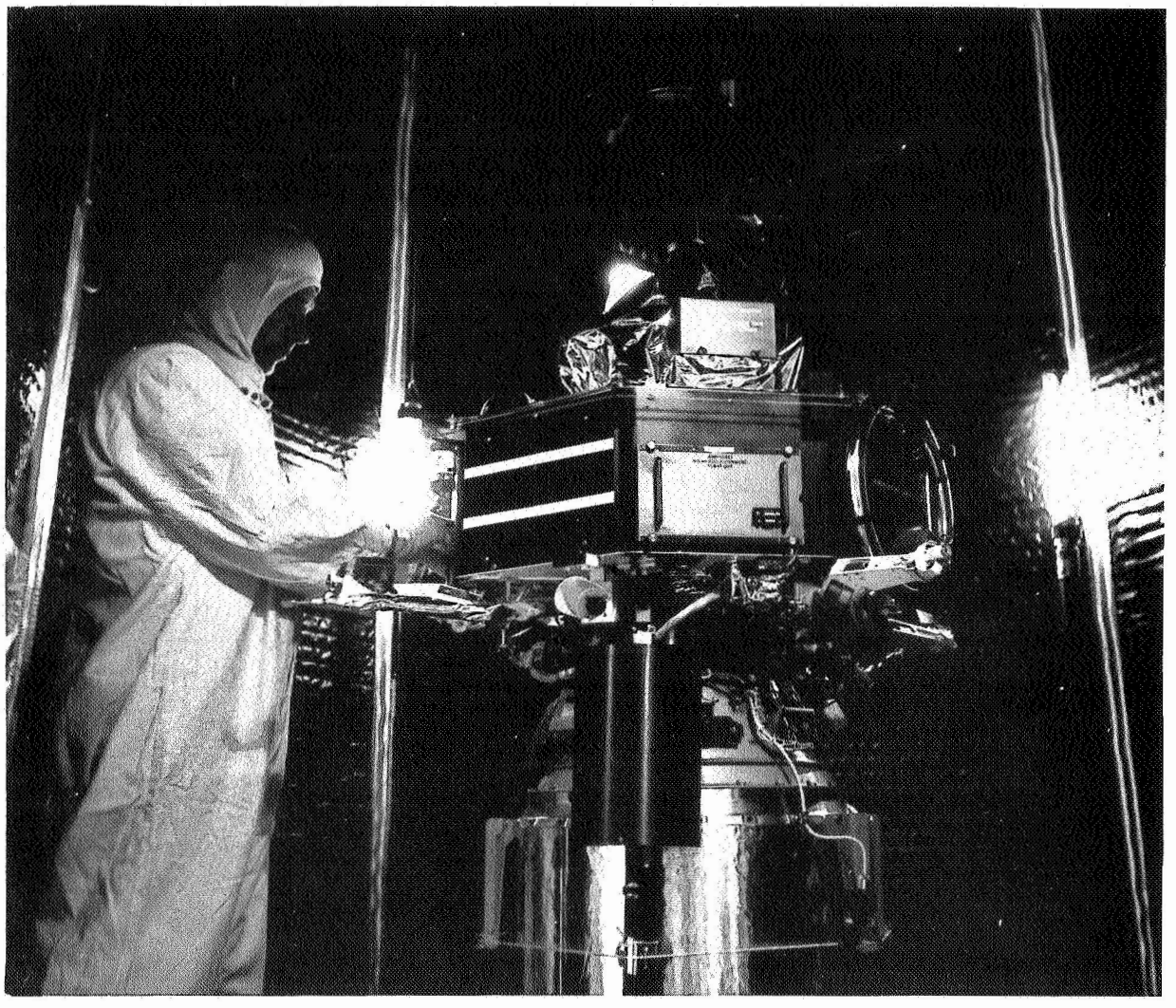

Figure 9. Technician Checking Paddle Arm Bracket
While under Gantry Air-Cooling Hat

microorganisms prior to decontamination, and not in excess of 2.7×10^4 microorganisms after the decontamination process. This constituted a 97% reduction of organisms. The estimation of viable internal burden of components (Table 2) was based upon past history and known manufacturing environments. It was determined that, of the total viable life remaining in the components, (see Table 4) 10% would be spore forms. Of this 10% approximately two-thirds would be aerobic and the remainder anaerobic.

As a result of the overall evaluation (Table 3) it was determined that at time of launch the Explorer XXXV spacecraft contained not in excess of 2.5×10^5 organisms. Of these an estimated 2.2×10^5 organisms were contained inside the components and foam encapsulant, and 2.7×10^4 organisms on the surfaces, and 7.4×10^3 of these on the surface were spores.

The Explorer XXXV spacecraft achieved a successful orbit with a life expectancy of three years and will have 1440 cycles of temperature change between -45° C

Table 1
Compilation of Viable Organisms on Surfaces

Area Class	Total Area (in^2)	Counts of Viable Organisms on Surfaces							
		Contaminated				Decontaminated			
		Aerobic		Anaerobic		Aerobic		Anaerobic	
		Veg.	Spores	Veg.	Spores	Veg.	Spores	Veg.	Spores
Occluded "A": Electronic Modules	8759	212899	62232	26858	25547	5937	3251	4099	55
Occluded "B": Surfaces that Module Frames Occlude	1138	4033	0	5914	0	72	0	3450	0
Occluded "C": Exterior of Module Frames	5813	56300	4489	9923	85	20	2030	192	0
Occluded "C": Other Interior Exposed Surfaces of the Spacecraft that the Cover Occludes	5195	20001	17467	898	40206	79	178	0	369
Interior Surfaces "D": Other Interior Surfaces of the Spacecraft —1 Body —2 Motor —3 Assembly Occluded	8490	63174	6517	8747	1750	1985	502	38	12
Exterior Surfaces "E": Exterior Surfaces of the Spacecraft —1 Body —2 Motor —3 Assembly Occluded	71437	228329	80818	19321	4344	3671	420	281	545
Final Totals of Contamination of the AIMP-E Spacecraft	Total 700.2 sq.ft.	584736	171523	71661	71932	11764	6381	8060	981
TOTALS		9×10^5				2.7×10^4			

Table 2
Compilation of Viable Organisms Contained Within Components

Components	Estimated Range	Number of Components	Accumulative Total x 10^3	
			Low	High
Resistors	0-1	11612	0	11.6
Capacitors	10-100	3153	31.5	326.9
Diodes	0-1	4005	31.5	330.9
Transistors	0-1	3164	31.5	334.1
Relays	100-1000	15	33.0	349.1
Crystals	0-1	1	33.0	349.1
Inductors	0 < 100	148	33.0	363.0
Toroids Transformers	0 < 100	117	33.0	375.6
Batteries	0	0	33.0	375.6
Metals	0	0	33.0	375.6
Tubes	0	4	33.0	375.6
Explosives	10	8	33.1	375.7
Foam	1/ml	14727 ml	47.8	390.4
Nylon-Dacron	0	876		
Teflon Insulation	0	16		
Magnetic Cores	0	0		
MOSFETS	0	747		
Pots	?	17		
Flat Paks	0	551		
Fuses	0	15		
Thermistors	0	35		
Estimated Total - Internal Burden			47.8	390.4
Average Internal Burden			219.0	

Table 3
Microbial Load at Launch AIMP-E Spacecraft

Type Load	Contamination Level
Internal Burden	2.2×10^5
Surfaces	2.7×10^4
Total Load	2.5×10^5

Table 4
Estimated Spore Loading at Launch and Lunar Impact

Area	Aerobic	Anaerobic	Totals
Surfaces	1.3×10^4	1.9×10^3	1.5×10^4
Internal Burden	1.5×10^4	7.3×10^3	2.2×10^4
Grand Totals	2.8×10^4	9.2×10^3	3.7×10^4
Remaining at Lunar Impact	1.89×10^{-9}		2.2×10^4

and +50° C in an ultra-high vacuum. Under this environment, the spore population on the exposed surfaces of the spacecraft should be reduced to 1.89×10^{-9} at time of lunar impact, and all vegetative life is assumed to exist no longer, only the components internal spore burden (2.2×10^4) would remain.

The Planetary Quarantine Officer, NASA Headquarters, recommended certification of the Explorer XXXV spacecraft based upon the evaluation of records maintained at the Goddard Space Flight Center, visual observations of control procedures, and assessment of the microbial environment of the spacecraft while in residence at the Eastern Test Range.

SUMMARY

1. Debris generating operations are performed in an uncontrolled area. Protection is afforded to flight hardware in near vicinity of debris generating operation.

2. Decontamination, conformal coating, and incapsulation of electronics are performed in class 10,000 clean-room. Area is restricted to numbers of personnel, clean-room dress, deportment, and procedure.

3. Spacecraft build-up, some engineering tests are performed in class 100,000 clean-room. Area is restricted to clean-room dress and deportment.

4. Instrument, hardware and spacecraft decontamination, assembly, experiment integration, bio-sampling and bio-assays are performed in a class 100 environment. The areas are restricted to number of personnel, clean-room dress, deportment and procedures.

5. Decontaminated instrument assembly and/or functional operation tests are conducted on class 100 horizontal laminar flow benches.

6. Small hand tools are cleaned and decontaminated, packaged, and sealed to retain level of cleanliness while in a class 100 white bench environment.

7. Prior to shipment to launch complex, spacecraft is dissassembled and precleaned in a class 10,000 clean room. Spacecraft interior final cleaning decontamination, bio-sampling and reassembly is performed in a class 100 bio-clean room. The area is restricted to number of personnel, specific clean room dress, and clean room deportment.

8. An electronic systems check-out is performed in field while the spacecraft is housed in a class 100 clean room environment and/or while protected by an asepsis covering.

9. Final check-out, decontamination and bio-sampling are conducted in class 100 environment in a laminar down flow cooling-hat shroud on the gantry. Spacecraft is bathed with class 100 filtered and temperature conditioned air until separation of service unbilical at time of lift-off.

APPENDIX
CLEAN ROOM REGULATIONS

General Clean Room Deportment

Personnel in any of the clean room areas observed the following clean room regulations and adjusted accordingly.

a. Individuals having respiratory or skin ailments are not allowed to work in the clean room areas.

b. Individuals with colds or severe sunburn are not permitted to work in clean room areas.

c. No unauthorized personnel are allowed in clean rooms.

d. Only test fixtures, tools, jigs and assembly fixtures needed to perform the required task are permitted in clean room.

e. No abrasives such as files, crocus cloth, etc., are permitted.

f. No shredding or masking tapes are permitted.

g. Exposed parts or components are not to be left on work benches.

h. Only approved clean room garmets will be worn in the various clean room areas.

i. No smoking or eating is allowed in clean rooms.

j. No person having cosmetics such as, after shaving talc, lip ice, etc., or external medication is allowed in clean room.

k. No pencils are allowed in clean room areas. Ball point pens and lint-free paper are permitted.

l. No horse-play will be tolerated. Movements are to be slow and rhythmic.

m. No watches and/or jewelry are to be worn while in the clean room areas.

n. Scratching head, eyebrows or exposed skin areas are taboo.

o. Coveralls are not to be unzipped when in the clean room areas.

p. No skin areas are to be exposed between gloved hand and coveralls.

q. Emergency exits will be used only in legitimate emergencies.

r. No equipment will be allowed in the clean room areas that has not been first pre-cleaned.

s. No more than two personnel will be allowed to work at one time under the Goddard Down Flow Unit.

t. Project and/or custodial personnel are not to disturb or be in the near vicinity of any clean room monitoring equipment.

Clean-Room Garments Required

Spacecraft Preparation Area

a. None, street clothes adequate

Hi-Bay Clean-Room Complex

a. Class 100,000 area: Shoe covers, cotton gloves and smocks.

b. Class 100 areas: Shoe covers, cotton or surgical-type gloves depending upon operation, smocks, and hats.

Bio-Clean-Room Complex

a. Class 10,000 area: Coveralls, shoe covers, cap, sterile gloves (surgical-type).

b. Class 100 bio-area: Shoe covers, coveralls, cap, hood, sterile rubber gloves (surgical-type), and face mask.

Gantry Cooling-Hat Shroud

a. Class 100 area: Shoe covers, velostate boots, leg stats, sterile rubber gloves (surgical-type), fire-proofed cap, hood, and coveralls.